RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
56 (6) 2216-2226, 2024
http://doi.org/10.54910/sabrao2024.56.6.4
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

GENETIC POTENTIAL OF THE PROMISING WINTER BARLEY (*HORDEUM VULGARE* L.) GENOTYPES IN ALMATY REGION, KAZAKHSTAN

A.Z. BAIMURATOV* **and B. SARIEV**

Kazakh Research Institute of Agriculture and Plant Growing, Almaty Region, Kazakhstan
*Corresponding author's email: baigas78@mail.ru
Email address of co-author: sariev.burubay@mail.ru

SUMMARY

In Kazakhstan, barley (*Hordeum vulgare* L.) grains are mainly for feed, food, and materials for brewing industries. Given the development of livestock farming and the processing industry, the Republics of Central Asia and Transcaucasia, Kazakhstan, are prime producers of grain crops used as feed. Similarly, a greater demand for barley grains is prevalent in countries like Iran, Turkey, and UAE. The presented study sought to assess the genetic potential of newly developed and promising winter barley cultivars, adaptive to specific zones and widely adaptable cultivars for cultivation in spacious areas. Climate change caused instability and a decline in yields; hence, stabilizing grain production over crop seasons and locations is one of the chief issues. The role of selection in local cultivars enhanced significantly; however, a conventional introduction cannot combat the negative influence of limiting environmental factors specific to particular zones. Therefore, developing highly productive and competitive barley cultivars adapted to local ecological conditions is highly relevant. The result of scientific research for 2020–2023 recognized 10 new barley cultivars for competitive varietal testing based on economically valuable traits.

Keywords: Winter barley (*H. vulgare* L.), high-yielding cultivars, climate change, temperature, precipitation, phenology, growing seasons, grain yield and quality, protein, starch

Key findings: The results revealed a weak relationship between the grain yield and quality indicators like starch and protein in winter barley (*H. vulgare* L.). The winter barley yield bears considerable influences from weather conditions, especially during the heading-ripening phase in Southeast Kazakhstan.

Communicating Editor: Prof. P.I. Prasanthi Perera

Manuscript received: March 02, 2024; Accepted: May 04, 2024.

Citation: Baimuratov AZ, Sariev B (2024). Genetic potential of the promising winter barley (*Hordeum vulgare* L.) genotypes in Almaty Region, Kazakhstan. *SABRAO J. Breed. Genet.* 56(6): 2216-2226. http://doi.org/10.54910/sabrao2024.56.6.4.

INTRODUCTION

In terms of area cultivated in Kazakhstan, the barley (*Hordeum vulgare* L.) crop ranks second after wheat. The spring barley mainly thrives in the central and northern regions of the country, while winter barley sowing mostly predominates the south and southeastern parts of Kazakhstan. In 2021, the area sown with spring barley comprised more than 2.225 million hectares, while winter barley has more than 3000 hectares (Bureau of National Statistics, Kazakhstan, 2021).

Primary stress factors that negatively affect the growth and development of crop plants are moisture deficiency, high temperatures, drought, hot winds, an early return of cold weather, salinization, and decreased soil fertility in the arable horizon of Kazakhstan. Therefore, if the rye and barley genotypes have no adaptability to a wide range of soil and climatic conditions, nor have the appropriate norm of response, these cannot withstand the various biotic and abiotic stresses effects (Goncharenko, 1996).

The predominance of additive gene interactions in controlling traits under the Aral Sea Region's environmental conditions indicates a possible effective selection in F_2 populations. However, in the Almaty Region's Piedmont zone, dominant genes managed the traits necessary to differentiate hybrid populations and carry out selection through several cycles to achieve the homozygosis of loci carrying dominant genes in spring barley (*H. vulgare* L.) (Tokhetova *et al*., 2022).

Barley productivity varies significantly in various cultivated areas. Therefore, an ecological testing should proceed to identify the cultivars' response to various soil and climatic conditions. It is an opportunity to identify crop genotypes that can adapt to specific soil and climatic conditions of a particular region. Ecological testing of winter barley cultivars progressed to identify drought-tolerant and adaptable winter barley cultivars, as well as, compare productivity of winter barley with spring barley in the arid central part of the Republic of Kalmykia for tangible findings (Goldvarg *et al*., 2020).

By studying the ecological adaptability and stability of winter barley cultivars, it was possible to identify the best responsive and stable genotypes to existing environmental conditions. Cultivars Erema, Master, and Pallidum-1952 were outstanding for their high responsiveness to improving growing conditions. The winter barley cultivars Marusya and Parallelum-1962 also provide consistently higher yields and can show better performance even under unfavorable environmental conditions (Filippov *et al.,* 2018).

Studying the grain yield and quality of winter barley cultivars in the eastern zone of the Rostov Region revealed that winter barley cultivars' yield was directly dependent on precipitation during the growing season. The prevailing hydrothermal conditions largely determined the said traits. The greatest adaptability of winter barley cultivation in the eastern zone of the Rostov Region resulted from cultivars Master, Timofey, and Erema, generating the highest grain yields (4.26, 4.18, and 4.37 t/ha, respectively) (Alabushev *et al.,* 2018). For the period 2014–2016, the study of 300 winter and 59 spring barley cultivars for disease resistance showed 117 winter and 37 spring cultivars with resistance during different crop seasons. Therefore, a stable host reaction to the pathogen in all growing zones occurred with the barley cultivars Zakari, AS-070418, Vivat, Skala, and Dali (Volkova and Astapchuk, 2019).

Nowadays, selection is becoming an integrating science and industry for producing new cultivars. Actively using a variety of physiological methods (Nichiporovich *et al.,* 1961) includes genetics (Cattivelli *et al.,* 2008; Smith *et al.,* 2008), biochemistry (Makowski and Klaas, 2000; Spunar *et al.,* 2004), and immunology (Vavilov, 1964; Abugalieva, 2005) to develop highly productive adaptive cultivars with specific grain qualities. It also determines its place in the market. Marker-assisted selection (MAS) is an additional tool for developing new cultivars that use highly polymorphic informative DNA markers. Currently, the marker-assisted selection has proven its value in enhancing the efficiency of barley breeding (Cuesta-Marcos *et al.,* 2016;

Genievskaya *et al.,* 2018; Almerekova *et al.,* 2019, 2021).

Past studies established that the main contribution to the formation of the grain yield came from selection traits associated with sowing density and the productivity of an individual plant (Surin *et al.,* 2023). Long-term results on applying nitrogen fertilizers showed that grain crops productively absorb nitrogen with partial application at the beginning of tillering and booting, respectively. By using nitrogen fertilizers, significant varietal differences were evident, with the nitrogen fertilizer absorption largely dependent on rates, timing, and fertilization methods (Ramazanova *et al.,* 2023). In modern conditions, the selection of winter barley pursued the development of high-yielding cultivars that are adaptive to nature's surprises. In addition to the varietal characteristics and environmental conditions, the crop that preceded sowing has a significant impact on the yield, and to maximize the yield level requires cultivating them on intensive predecessors (Zasypkina and Filippov, 2023).

Producers need to select a variety of winter crops to produce grain crops in arid climates effectively. For this purpose, environmental testing of winter wheat and barley cultivars commenced under the typical climatic conditions of the Lower Volga Region of Russia. The maximum biological yield (6.4 t/ha) resulted from the winter barley variety Buran due to more number of productive shoots (440 pcs/m2), and cultivar Voskhod (4.9 t/ha) due to the highest grain weight per ear (1.46 g) (Sukhareva and Belikina, 2023).

In past studies, the soil moisture apparently emerged less significant compared with meteorological factors. With the expected climate change, the excess precipitation and heat stress deserve more attention in breeding and crop modeling (Lischeid *et al.,* 2022). In Kazakhstan, the use of barley grains is only for feed purposes, as a source of protein and lysine. However, barley is a widely used crop abroad for food and dietary purposes and as a source of high content of β-glucans (Sariev and Baimuratov, 2020). The enhanced yield mainly depends upon the factors of improving the farming culture and on the genotypes, which is vital in increasing the yield per unit area. The presented study aspired to assess the genetic potential of newly developed promising winter barley cultivars, adaptive to specific zones, as well as, widely adaptable cultivars for cultivation in spacious areas.

MATERIALS AND METHODS

Breeding material and research procedure

The genetic material comprised 30 winter barley (*Hordeum vulgare* L.) genotypes selected from a large population. Cultivar 'Aydin' was the sample used as standard genotype, with the data about its agronomic and yield-related traits provided in Tables 1 and 2. The field experimental station of the grain forage crops is located in the foothill zone of the Almaty Region, Kazakhstan. Field experiments on selected winter barley genotypes proceeded by following the methodology of Dospekhov (1985) and the State Committee for Social Sciences of the Republic of Kazakhstan (2002). Formation of nurseries in successive stages of the selection process commenced according to the 'Arpa Comprehensive Program' (1983). In the barley selection, phenological observations employed the VIR method (1973) and the international SEV classifier of the genus *Hordeum* (1983). Assessment for stressful environmental conditions about the drought resistance also ensued (Balyk, 1979; Kozhushko, 1988; Oleynikova *et al*., 1985).

The study on grains biochemical composition used the following methodology: Nitrogen content estimation by the Kjeldahl method, with protein content recalculated to 6.25; starch content determination by the polarimetric method, with the amylose content determined by the iodometric method, including a NIR basis; and cereal quality, brewing, and feed properties assessment in accordance with relevant GOSTs (Savin *et al.,* 1998).

Table 1. Winter barley genotypes with biological properties averaged over three years (2021–2023).

Genotypes	Biological properties						
	Days to booting (days)	Days from booting to heading (days)	Days from heading to full ripening (days)	Growing season (days)	Plant height (cm)	Last internode length (cm)	Spike type
Aydin - Standard	19	18	43	237	81.6	21.4	multi-row
40/16-10	20	19	40	235	85.2	18.5	double-row
76/13-1	19	18	41	235	87.1	17.5	double-row
76/13-4	20	20	40	237	98.7	23.9	double-row
71/12-8	19	23	40	238	99.3	21.6	double-row
10/16-2	20	21	38	235	95.6	26.4	multi-row
71/13-3	17	24	42	237	84.6	14.1	double-row
8/16-11	19	20	42	238	103.3	25.3	double-row
11/16-5	18	20	41	234	92.4	21.5	double-row
11/16-2	17	21	41	237	94.6	20.9	double-row

Table 2. Winter barley genotypes' performance for quantitative and qualitative traits averaged over three years (2021–2023).

Genotypes	Economically valuable traits					Quality indicators of grain	
	Productive tillering capacity (#)	Spike length (cm)	Grains per spikelet (#)	1000-grain weight (g)	Productivity (t/ha)	Protein content in grains (%)	Starch content in grains (%)
Aydin - Standard	2.6	7.2	56.4	41.7	2.62	15.0	56.0
40/16-10	2.5	8.3	23.9	47.5	2.87	16.3	56.1
76/13-1	2.3	8.8	27.4	47.5	3.42	15.2	56.2
76/13-4	2.3	8.5	24.1	49.0	3.17	16.6	54.5
71/12-8	2.6	8.9	25.0	42.8	2.85	15.4	55.2
10/16-2	2.6	7.6	59.9	43.2	3.5	15.7	55.6
71/13-3	2.3	7.4	21.5	49.5	3.02	15.5	53.5
8/16-11	2.4	10.2	27.5	52.4	3.04	15.8	55.5
11/16-5	2.2	8.5	22.8	57.0	3.09	14.9	55.9
11/16-2	2.2	9.7	25.9	55.2	2.98	15.3	55.8

RESULTS AND DISCUSSION

The Almaty Region, in the southeastern part of Kazakhstan, has enclosures on several sides by mountain ranges. From the South, the spurs of the Tien Shyan, from the North by the Chingiz-Tau ridge, and from the east has the borders of the Tarbagatai, Dzhungar Alatau, and other ridges. Given the complexity of the surface structure and the difference in altitude above sea level, the climate of the region is very diverse. This diversity also includes both the precipitation and temperature conditions. The weather conditions are relatively mild, generally characterized by hot summers, warm and dry autumns, relatively mild winters, and wet and cool springs. The snow cover falls at the end of November and at the beginning of December, and its depth reaches 20–25 cm. The sub-zero temperatures last for 3–4 months. The coldest month is January, while the hottest is July.

In 2020–2022, in the Samara Region of the Russian Federation, a study happened on the influence of natural and climatic conditions on the formation of yield indicators and protein content in winter wheat grains. In the said study, the various studied parameters bore influences from natural and climatic conditions, as well as, genotypic characteristics of the studied cultivars, which explored the diverse relationship dependence (Sharapov *et al.,* 2023).

In 2021–2023, this region had the crop seasons characterized by high air temperatures and extremely low precipitation. Figure 1 shows the main agrometeorological indicators determining the growth and development of winter barley during the research years at a semi-sufficient rainfed laboratory of grain fodder crops. In South Kazakhstan and Central Asia, barley growing occurs during autumn predominantly. Under these environmental conditions, drought is the most critical cause of the grain yield reduction. Additionally, barley cultivars should be resistant to fluctuations in average annual precipitation, sometimes very significant. The task of combining various economically valuable and biological features in one cultivar requires processing a large collection developed at the national and foreign breeding institutions (Mussabaev *et al.,* 2018).

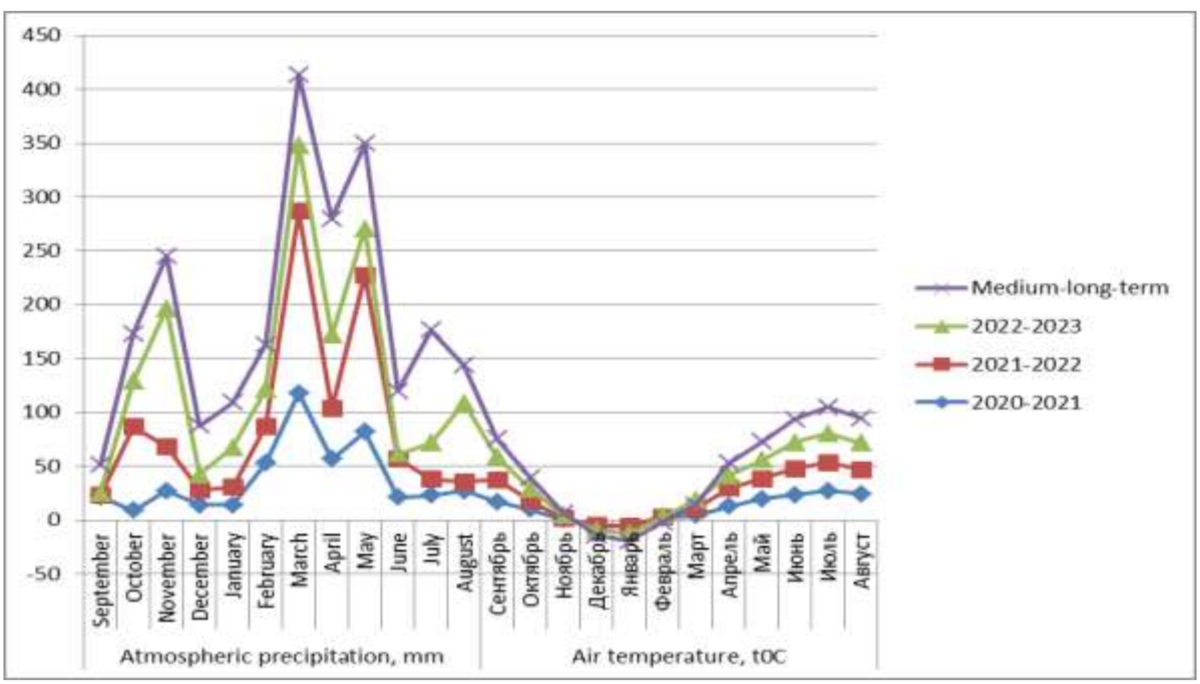

Figure 1. Meteorological conditions for the growing season of plants 2020–2023, Almalybak weather station, Kazakh Research Institute of Agriculture and Plant Growing, Almaty Region, Kazakhstan.

The sowing of presently selected barley genotypes commenced on October 5, 2020, with seedlings appearing on November 10, 2020, and the autumn growing season stopped at three to four leaf stage. Spring shoots appeared in late March and early April. For winter barley, the growing season in 2020–2021 ranged from 238 to 242 days. Weather conditions during the growing season differed from the long-term average. The temperature regime was 1744 °C, with an average of 7.17 °C. Precipitation for the entire growing season was 384.5 mm, with a snow cover of 5 cm. However, according to long-term data, the amount of precipitation was 698.9 mm, and the snow cover was 11 cm. The total temperature from tillering to booting of winter barley ranged from 368.9 °C to 457.2 °C, with an average of 16.0 °C. The precipitation was 100.0 mm, and from booting to heading, the total temperature ranged from 292.6 °C to 394.8 °C. The atmospheric precipitation was 16.7 mm, the total temperature ranged from 764.8 °C to 1013.6 °C from earing to plant ripening, the amount of precipitation was 22.4 mm, and the air humidity ranged from 65.6% to 66.07% during the spring growing season.

Analysis of long-term data (2014–2019) showed that in various agrometeorological conditions of environmental testing, the cultivar Rafael displayed considerable increased productivity compared with the standard cultivar Jaromir and other earlier selected cultivars (Levakova *et al.,* 2023). The winter barley sowing in 2021 was on October 13. The friendly shoots appeared on November 1, 2021. In the autumn growing season, the winter barley stopped at the four-leaf phase. Spring shoots appeared at the end of March. The growing season for winter barley in 2021–2022 ranged from 237 to 242 days. The temperature regime was 2039 °C, with an average of 8.42 °C, while according to long-term data, the average temperature was 8.6 °C, with a snow cover of 6 cm. In winter barley, the temperature from tillering to booting ranged from 131.6 °C to 237.6 °C, with an average of 13.16 °C, and the amount of precipitation was 26.3 mm. From booting to heading, the total temperature was 232.2 °C to 397.4 °C, and the amount of precipitation was 81.8 mm. From earing to plant ripening, the total temperature ranged from 937.8 °C to 1108.6 °C, and the precipitation was 59.4 mm.

The growing of selected barley genotypes during two seasons had different levels of water deficiency (the precipitation was 15% in the first year, and 36% during the second year of the growing season, and lesser than the long-term precipitation average). Significant differences were evident in the direction of a correlation between the grain yield and yield-related traits during both growing seasons (Dyulgerova and Dyulgerov, 2023a, b). In 2022, the sowing of winter barley genotypes took place on October 22, and the shoots appeared after 18 days. In autumn, the winter barley stopped at the two-three leaf stage, and the spring shoots appeared in early April. The winter barley-growing season ranged from 230 to 238 days. The temperature regime was 1670 °C, with an average of 7.1 °C, snow cover of 7.2 cm, and precipitation of 403.1 mm, compared with the long-term average of 698.9 mm. From tillering to booting of winter barley, the total temperature ranged from 165.0 °C to 264.2 °C, and the precipitation was 35.4 mm. During booting to heading, the total temperature was 372.4 °C to 531.8 °C, and the precipitation was 46.2 mm. From earing to plant ripening, the total temperature ranged from 842.5 °C to 941.7 °C, and the precipitation was 21.6 mm.

Moisture deficiency and elevated temperatures in the pre- and post-sowing periods prevented the plants to bloom, and the winter barley stopped the autumn growing season at the 3-4 leaf phase. During crop seasons 2021–2023, the studied winter barley genotypes against the natural background for susceptibility to smut diseases (dusty and hard) during the heading and full ripeness phase, smut diseases were absent. An immunological assessment of 10 cultivars of winter barley of domestic and foreign selection in the germination phase revealed that two cultivars appeared resistant to net leaf spot, with scores for Vivat (1.7) and Kvant (1.6). Cultivars Artel (3.8), Fox-1 (2.3) of domestic selection, and cultivar Carioca (2.7) of foreign selection showed moderate resistance. Field moderate resistance in percentage emerged in four cultivars of winter barley, i.e., Vivat (18.3), Kvant (26.6), Marusya (19.9), and Fox-1 (24.9) (Volkova *et al.,* 2023).

According to biological characteristics, the identified winter barley genotypes were 11 samples, with 234–236 days as per the length of growing season. For plant height, 19 samples identified showed a range from 85.0 to 105.0 cm. One of the morphological tests of drought resistance relied upon the length of the last internode. According to this indicator, 14 genotypes indicated lengths of 17.0–32.0 cm. Based on morphological and agronomic traits of seven hull-less mutants of the winter barley variety Akhil, the study revealed that mutant lines had 20%–42% lower grain yield than the parental lines. In the said study, close correlations of the spikelets per square meter and winter hardiness occurred with grain yield, making it possible to use these traits in the selection of high-yielding cultivars (Dyulgerova and Dyulgerov, 2020).

According to economically valuable indicators, 21 samples (2.3–3.5 pieces) were notable, according to productive bushiness, i.e., grains per ear, 16 samples (22.0–32.0 pieces) for two-row forms, four samples (60.0–72.0 pieces) for six-row forms, and for 1000-seed weight, 12 samples (50.0–54.0 g) were distinct. In past studies on 18 two-row barley genotypes, the regression equation showed that grain weight per ear depends on the grains per ear and 1000-grain weight (Popova and Valcheva, 2021). By selecting oats, barley, and wheat genotypes for increased stability by 1000-grain weight, grain size will not decrease (Polonsky *et al.,* 2023).

For quality indicators, such as, protein and starch content in grains, 17 samples surfaced. As shown in Tables 1 and 2, the characteristics of biological properties, economically valuable traits, and quality indicators manifested for 10 genotypes of winter barley, which differed in positive characteristics of biological properties, economically valuable traits and grain quality. From Table 1, the selected cultivars of winter barley belong to medium-ripe forms, and the growing season length was 234–237 days. The study established that traits associated with sowing density (plants before harvesting, productive stems, and tillering) and the productivity based on an individual plant (grain weight per plant and 1000-grain weight) mainly contributed in the formation of grain yield (Surin *et al.,* 2023).

Overall, in barley genotypes, the plant height ranged from 81.6 to 103.3 cm, which characterizes their resistance to lodging. Table 2 details the selected cultivars that showed the high productive tillering, which ranged from 2.2 to 2.6 stems. According to grains per ear, two-row ones had 22.8 to 27.5 grains, and six-row ones had 56.4 to 59.9 grains, while the 1000-grain weight ranged from 41.7 to 57.0 g. The grain yield in these winter barley genotypes averaged from 2.85 to 3.43 t/ha over the three years of study. The standard variety Aydin exhibited a record grain yield of 2.62 t/ha. The protein content in grains of the selected genotypes ranged from 15.8% to 18.0%.

Seventeen winter barley cultivars underwent evaluation over three-growing seasons (2018/2019, 2019/2020, and 2020/2021). Based on the GYT biplot and Pearson correlations, a positive correlation of grain yield with lodging resistance and spikelets per square meter was established. However, the negative correlation of grain yield with plant height and 1000-grain weight was evident. The results of the presented study further revealed that the GYT biplot approach could help identify the winter barley genotypes with the best combination of yield with other traits and improve the genotype selection based on multiple traits in a feed barley-breeding program (Dyulgerov and Dyulgerova, 2023a, b).

Analyzing the results of traits association during crop seasons 2021–2023 established (Table 3) the relationship between the grains' starch and the characteristic of the growing season, booting and heading. The correlation showed with an inverse relationship (-0.790**), with yield indicators having a weak inverse correlation (-0.632*). For protein indicators, a negative correlation occurred between heading-ripening (-0.917**) and yield indicator (-0.875**). However, the plant height was in a positive correlation with the last internode length (0.801*) and heading-

Table 3. Correlation between phenological, quantitative, and qualitative traits in winter barley genotypes.

Traits	Tillering-booting (days)	Booting-heading (days)	Productive tillering (#)	Starch(%)	Productivity (t/ha)	1000-grain weight (g)	Grains ear^{-1}	Growing season (days)	Last internode length (cm)	Heading – ripening (days)	Ear length (cm)	Protein (%)	Plant height (cm)
Tillering-booting (days)	-												
Booting-heading (days)	-0.563	-											
Productive tillering (#)	-0.157	-0.037	-										
Starch (%)	0.290	-0.790**	0.118	-									
Productivity (t/ha)	-0.459	-0.271	0.319	0.632*	-								
1000-grain weight (g)	-0.083	-0.204	-0.314	0.359	0.308	-							
Grains ear^{-1}	-0.032	-0.026	0.353	-0.091	-0.014	-0.507	-						
Growing season (days)	-0.146	-0.287	0.255	0.507	0.585	0.120	-0.071	-					
Last internode length (cm)	-0.531	0.087	0.292	0.145	0.632	0.078	0.253	0.452	-				
Heading to ripening (days)	-0.526	-0.275	0.221	0.540	0.852*	0.225	-0.036	0.708*	0.608	-			
Ear length (cm)	-0.023	0.096	0.054	-0.274	-0.214	0.202	-0.213	0.109	-0.065	-0.228	-		
Protein (%)	0.562	0.224	-0.265	-0.555	-0.875**	0.232	-0.039	-0.614	-0.573	-0.917**	0.216	-	
Plant height (cm)	-0.599**	0.215	0.128	0.122	0.606*	0.305	-0.074	0.459	0.801*	0.524	0.164	-0.528	-

*, **: Significant at $P \leq 0.05$ and $P \leq 0.01$, respectively

ripening with grain yield (0.852*). Multi-climatic field trials progressed over four crop seasons and showed a highly significant ($P \leq 0.001$) cultivar effect for all the examined traits. Performance index (PIABS) of cultivars in both treatments had a negative nonsignificant correlation with grain yield and grain yield stability in the same cultivars in multi-climate field trials (Kovačević *et al.,* 2015). Dispersion analysis of protein, starch, yield, and 1000-grain weight showed (F-index) F-71.743, F-192.534, F-153.714, and F-2.726, respectively (Figure 2).

CONCLUSIONS

The lack of precipitation during the sowing period of winter barley (*H. vulgare* L.) against the background of elevated air temperatures caused a significant thinning of seedlings, weak tillering of plants, affecting the grain filling. Harsh weather conditions contributed to the successful grading of the breeding lines for drought resistance. Based on the comprehensive assessment of biological properties, economically valuable traits, and quality parameters, the selected winter barley genotypes meet the requirements of the food and feed industry.

ACKNOWLEDGMENTS

This study received financial support from the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan within the framework of the IRN grant AP19678544 “Creation of a forms facultative barley based on breeding and biotechnology methods for cultivation on rainfed and non-irrigated lands of Kazakhstan,” under the budget program 217 "Development of Science," subprogram 102 Grant financing of scientific research priority "Sustainable development of the agro-industrial complex and safety of agricultural products."

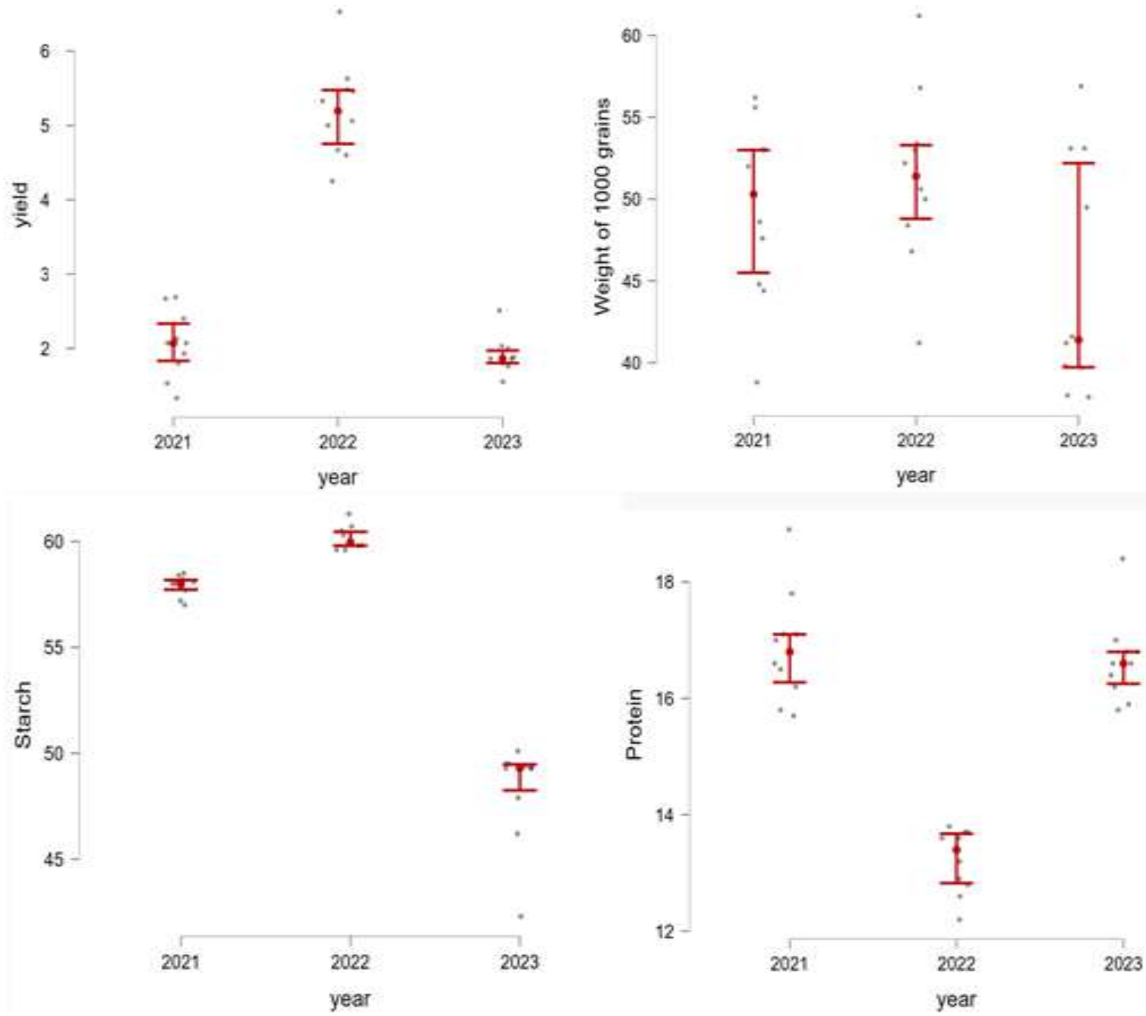

Figure 2. Analysis of variance of quantitative and qualitative indicators of winter barley genotypes.

REFERENCES

Abugalieva AI (2005). Biochemical testing of grain quality as the basis for the classification of barley genetic resources. *Biotechnol. Theor. Pract.* 1: 14–25.

Alabushev AV, Popov AS, Lysenko AA, Yatsenko VA (2018). Productivity and quality of winter wheat varieties in the eastern part of the Rostov region. *Grain Eco. Russia.* 4: 21–24.

Almerekova S, Genievskaya Y, Abugalieva S, Sato K, Turuspekov Y (2021). Population structure and genetic diversity of two-rowed barley accessions from Kazakhstan based on SNP genotyping data. *Plants* 10. 2025. https://doi.org/10.3390/plants10102025

Almerekova S, Sariev B, Abugalieva A, Chudinov V, Sereda G, Tokhetova L, Ortaev A, Tsygankov V, Blake T, Chao S (2019). Association mapping for agronomic traits in six-rowed spring barley from the USA harvested in Kazakhstan. *PLoS ONE* 14.

Balyk GS (1979). Selection of varieties for drought resistance and productivity by roots. Methodical instructions. pp. 49.

Bureau of National Statistics, Kazakhstan (2021). Bureau of National Statistics Strategic Planning and Reforms Agency of the Republic of Kazakhstan (https://stat.gov.kz/official/industry/14/statistic/6).

Cattivelli L, Mastrangelo A, Rizza F, Badeck F, Mazzucotelli E, Marè C, Crosatti C (2008). Integrated aspects from breeding to genomics of the abiotic stress response: The case of drought. 10th International Barley Genetics Symposium, 5-10 April 2008, Alexandria, Egypt, pp. 35–39.

Comprehensive Programme of Barley Breeding for Areas of the Eastern Breeding Center 'ARPA' (1983). Methodological recommendations. - Alma-Ata: 36 p.

Cuesta-Marcos A, Kling JG, Belcher AR, Filichkin T, Ulrich SE (2016). *V. Barley:* Genetics and Breeding. Encyclopedia of Food Grains (Second Edition). 4: 287–295.

Dospekhov BA (1985). Field Experience Methodology (with the basics of statistical processing of research results). Agropromizdat, Moscow, pp. 351.

Dyulgerov B, Dyulgerova N (2023b). Application of genotype by yield x trait biplot approach for selection of winter barley varieties. *Bulg. J. Agric. Sci*. 29(6): 1096–1102.

Dyulgerova B, Dyulgerov N (2020). Evaluation of hulless mutants of winter barley. *Agric. Conspectus Scientificus* 85(3): 203–209.

Dyulgerova B, Dyulgerov N (2023a). Evaluation of genetic parameters of winter barley varieties under water deficit conditions. *J. Cent. Eur. Agric.* 24(4): 862–872.

Filippov EG, Dontsova AA, Bragin RN (2018). The assessment of ecological plasticity and stability of winter barley varieties and lines. *Grain Eco. Russia.* 2: 11–13.

Genievskaya Y, Almerekova S, Sariev B, Chudinov V, Tokhetova L, Sereda G, Ortaev A, Tsygankov V, Blake T, Chao S (2018). Marker-trait associations in two-rowed spring barley accessions from Kazakhstan and the USA. *PLoS ONE* 13.

Goldvarg BA, Boktaev MV, Filippov EG, Dontsova AA (2020). Ecological testing of the winter barley varieties in the conditions of Republic of Kalmykia. *Grain Eco. Russia.* 3: 48–51.

Goncharenko AA (1996). Creation of source materials for winter rye with group resistance to diseases. *Breed. Seed Prod*. 3-4: 13–20.

Guidelines for studying the world collection of barley and oats. L., 1973. pp. 30.

International classifiers of CMEA of the genus *Hordeum L* (1983). L. pp. 53.

Kovačević J, Mazur M, Lalić A, Antunović J, Cesar V (2015). Photosynthetic performance index in early stage of growth, water use efficiency, and grain yield of winter barley cultivars. *Chilean J. Agric. Res.* 75(3): 275–283.

Kozhushko NN (1988). Assessment of drought resistance of field crops. Diagnostics of plant resistance to stress. Methodological guide. Leningrad, pp. 10–25.

Levakova OV, Gladysheva OV, Eroshenko LM (2023). New spring barley variety 'Rafael' adapted to the conditions of the Central region. *Grain Eco. Russia* (1): 42-49.https://doi.org/10.31367/2079-8725-2023-84-1-42-49.

Lischeid G, Webber H, Sommer M, Nendel C, Ewert F (2022). Machine learning in crop yield modelling: A powerful tool, but no surrogate for science. *Agric. For. Meteorol.* 312: 108698.

Makowski N, Klaas H (2000). Braugerste mit Sommer und wintergerstenform produziezen. *Getreide. Mag.* 6.1: 62–65.

Methodology State Strain Testing of Crops (2002). Almaty: Ministry of Agriculture CRC: pp. 339.

Mussabaev ZS, Meirmanov GT, Ortaev AK, Kirchev H (2018). The selection of parental material for winter barley breeding in boharic direction. *Ecol. Environ. Conserv.* 24(4): 1645–1650.

Nichiporovich AA, Stroganova LE, Chmora SN, Vlasova GP (1961). Photosynthetic Activity of Plants in Crops. M: Kolos, pp.130.

Oleynikova TV, Kozhushko NN, Osipov YuF (1985). Drought Resistance. Moscow, pp. 246.

Polonsky VI, Sumina AV, Gerasimov SA, Kolichenko AA (2023). Higher stability of oat, barley and wheat accessions in their 1000-grain weight is not associated with a smaller grain size. *Proceedings on Appl. Bot. Genet. Breed*. 184(2):52–65. (In Russian) https://doi.org/10.30901/2227-8834-2023-2-52-65.

Popova T, Valcheva D (2021). Analysis of two-row barley accessions by commercial traits for selection purposes. *Bulg. J. Agric. Sci.* 27(6): 1143–1146.

Ramazanova SB, Kenenbaev SB, Gusev VN, Baymakanova GSh (2023). Nitrogen fertilizers role in grain crops productivity in South-East Kazakhstan. *SABRAO J. Breed. Genet.* 55(5): 1812–1820. http://doi.org/ 10.54910/sabrao 2023.55.5.32.

Sariev B, Baymuratov AZh (2020). Results of the creation of new varieties of grain fodder crops in Kazakhstan and its implementation in production. *KazNAU Res. Results* 3: 311–317.

Savin VN, Abugaliev IA, Abugalieva AI (1998). Analytical research in crop production. *Reports of RAAS.* 2: 13–15.

Sharapov II, Sharapova YuA, Abdryaev MR (2023). Influence of weather conditions on yield and protein content in winter wheat grain. *Siberian Herald Agric. Sci*. 53(9): 40–48. (In Russian) https://doi.org/10.26898/0370-8799-2023-9-5.

Smith DS, McKay, Eckermann, Eglinton JK (2008). Investigating root architecture in barley and responses to salinity and high boron coventry. 10th International Barley Genetics Symposium, Alexandria, Egypt, (5-10 April 2008): 40–45.

Spunar J, Spunarova M, Nesvadba Z, Vaculova K (2004). Comparison of malling quality parameters of spring and winter barley genotypes in the Czech Republic. *Czech J. Genet. Plant Breed.* 40: 104.

Sukhareva EP, Belikina AV (2023). Evaluating winter grain crops varieties suitable for the Lower Volga region of Russia. *Res. on Crops* 24(1): 41–46.

Surin NA, Gerasimov SA, Lyakhova NE (2023). Adaptability and ecological plasticity of barley under forest-steppe conditions of the Krasnoyarsk Territory. *Siberian Herald Agric. Sci*. 53(6):15–23. https://doi.org/10.26898/0370-8799-2023-6-2.

Tokhetova LA, Makhmadjanov SP, Savin TV, Baimbetova GZ (2022). Combining ability analysis in spring barley (*Hordeum vulgare* L.) for yield traits. *SABRAO J. Breed. Genet*. 54(4): 710–721. http://doi.org/10.54910/sabrao2022.54.4.3.

Vavilov NI (1964). Problems of immunity of cultivated plants. Ed. Proceedings. Novosibirsk: Nauka pp.52.

Volkova GV, Astapchuk IL (2019). Distribution of PYRENOPHORA TERES on barley crops in the North Caucasus region. *Grain Eco. Russia* 2: 63–68.

Volkova GV, Yakhnik YaV, Danilova AV (2023). Immunological assessment of winter barley cultivars against leaf net blotch. *Siberian Herald Agric. Sci*. 53(7): 48–56. (In Russian) https://doi.org/10.26898/0370-8799-2023-7-6.

Zasypkina IM, Filippov EG (2023). Estimation of winter barley varieties according to productivity and adaptability indicators in the conditions of the Lower Don. *Grain Eco. Russia* 1: 56–63. https://doi.org/10.31367/2079-8725-2023-84-1-56-63.